The US Particle Accelerator School
Ion Pumps

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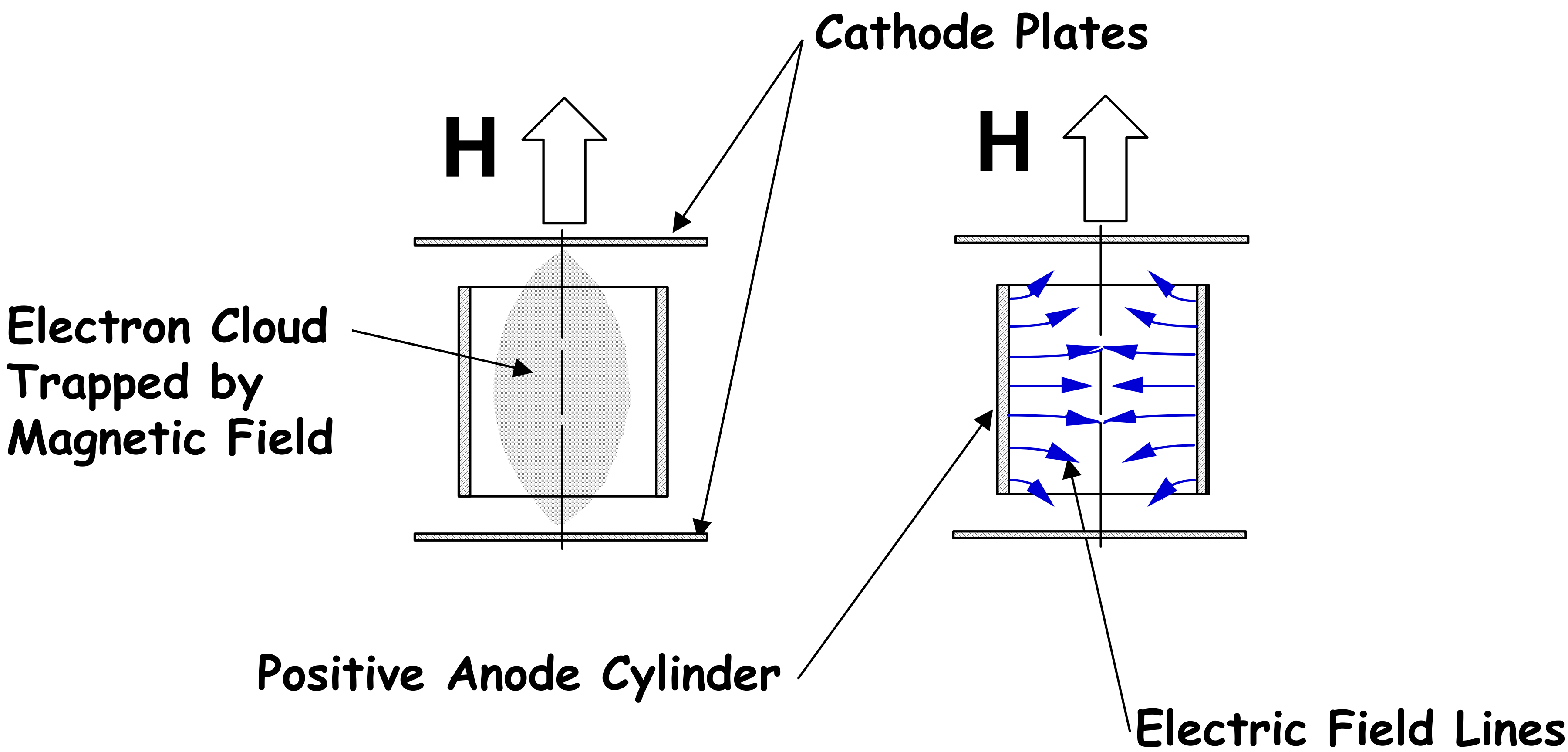
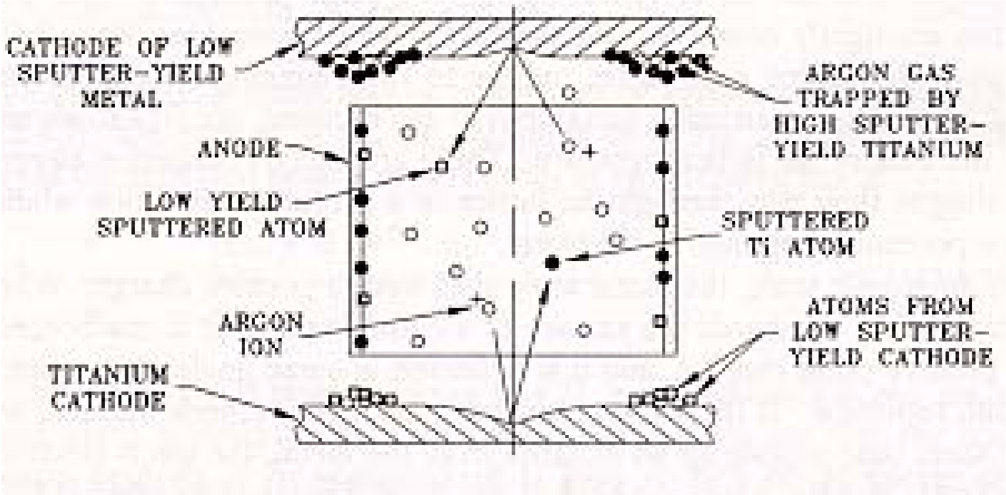
Penning Cell



Pumping mechanism

- Electrical discharge takes place in crossed electric and magnetic fields.
- The Titanium cathode is bombarded by positive ions.
- Titanium is sputtered on to to the walls of the anode.
- Gas chemisorbs to the sputtered Titanium.
- Gas is buried in the Titanium cathode.



Sputter Ion Pumping Mechanisms

Physisorption - atom burial deep within a lattice, atom burial under sputtered material.

Chemisorption - removal of atoms due to the formation of chemical bonds.

Diffusion - hydrogen diffuses into the bulk of the metal.

Sputter-ion pump characteristics

- Pumping speed - is sensitive to gas species, inlet size, pressure, and history of pump
- Starting pressure - ion pumps must be roughed to 20 milliTorr or less before starting (should be more like 10^{-6} Torr)
- Capacity - sputter ion pumps are gas capture type pumps and do have a limited capacity

Advantages

- Ultra clean
- Quiet
- High pumping speed for water, hydrogen

Disadvantages

- Gas species sensitive
- Limited capacity

Characteristic Parameter of Penning

Penning Cell Sensitivity

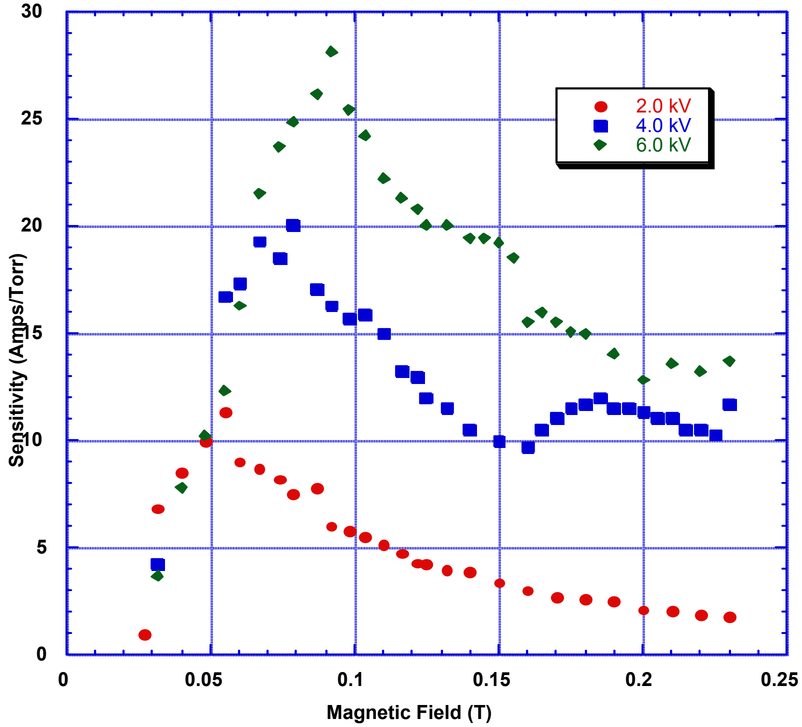
$$S = \frac{I^+}{P}$$

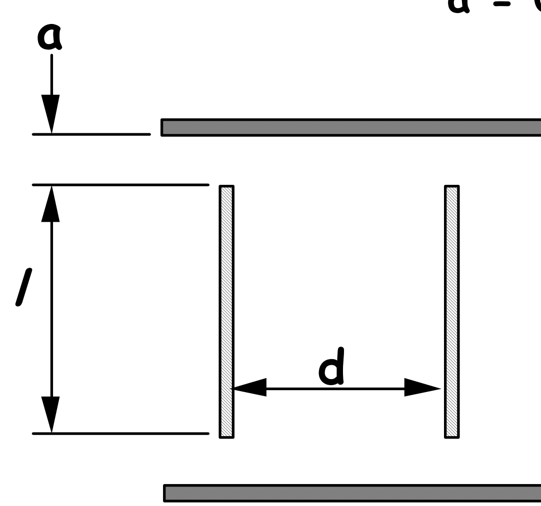
Where I^+ = ion current (Amps)
P = pressure (Torr)

Parameters that effect Penning Cell Sensitivity and typical values

Anode Voltage	V	3.0 - 7.0 kV
Magnetic Field	B	0.1 - 0.2 T
Cell Diameter	d	1.0 - 3.0 cm
Cell Length	l	1.0 - 3.2 cm
Anode/Cathode Gap	a	0.6 - 1.0 cm
Pressure (P^n)	P	$1.05 \le n \le 1.5$ Torr

Penning cell sensitivity as a function of magnetic field and anode potential

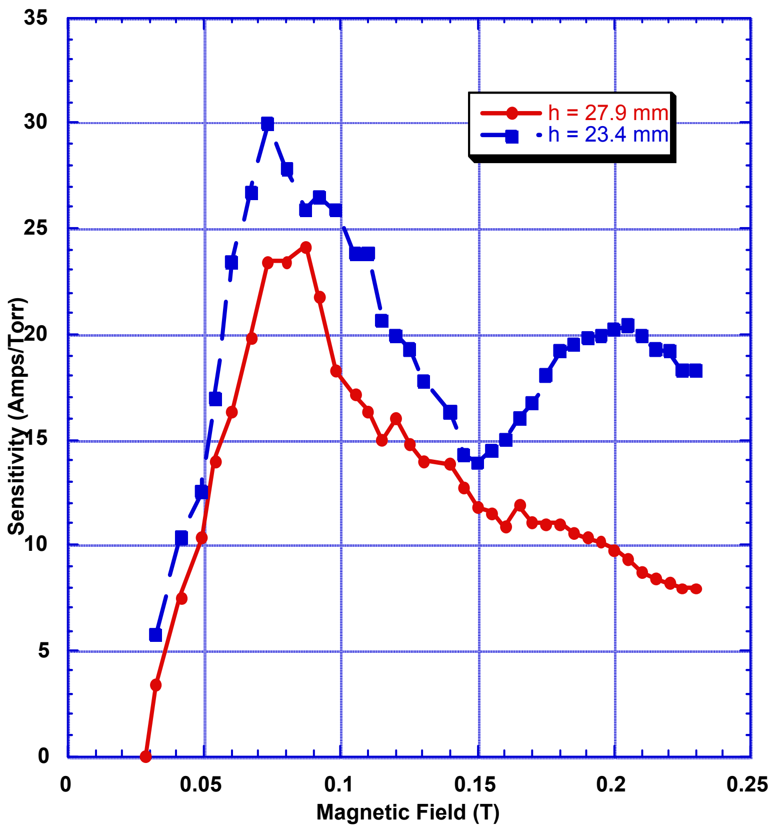




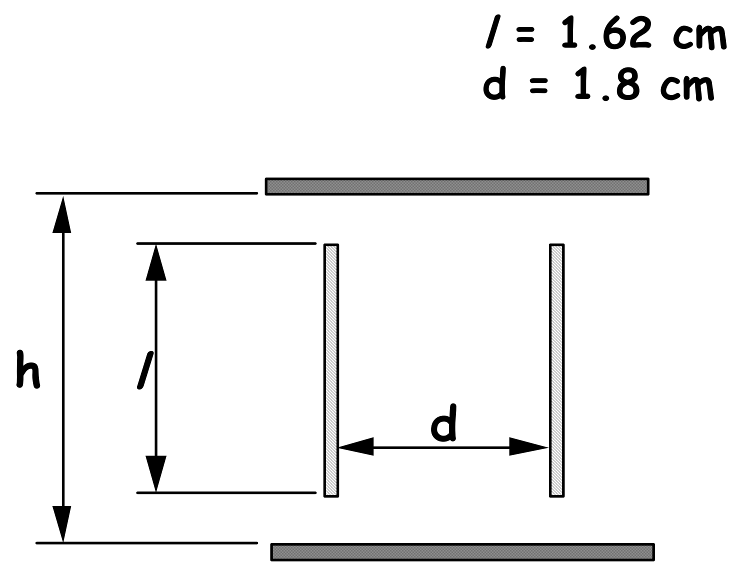
l = 1.62 cm
d = 1.8 cm
a = 0.6 cm

(Ref., Welch, SLAC, 1969)

Penning cell sensitivity as a function of magnetic field and anode-to-cathode spacing



(Ref., Welch, SLAC, 1969)



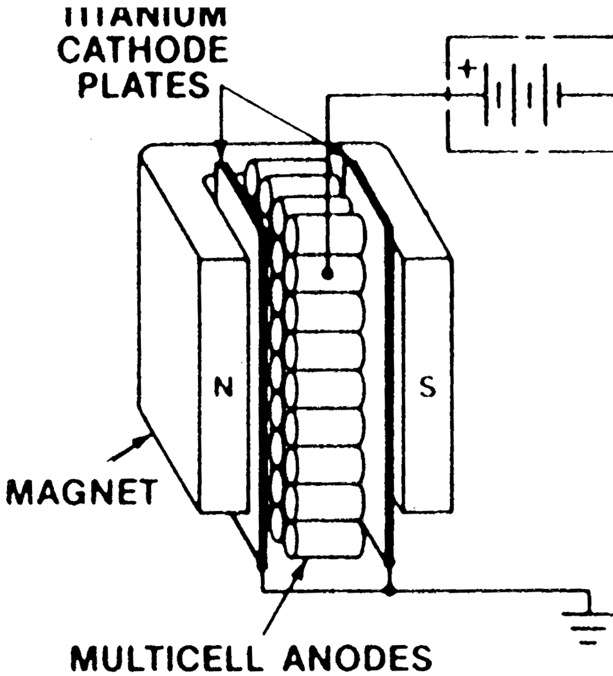
Types of sputter-ion pumps

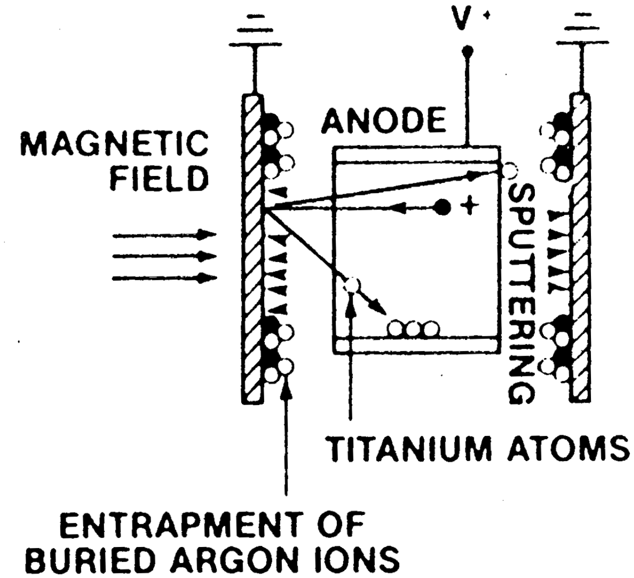
- **Diode** - best for UHV systems where 98% of the gas is hydrogen. Diodes have the highest hydrogen pumping speed.

- **Differential (Noble Diode)** – a compromise for hydrogen pumping speed with limited argon stability. This pump has reduced hydrogen pumping speed.

- **Triode/Starcell** - good hydrogen pumping speed, also pumps argon well. Good choice for pumping down from higher pressures often.

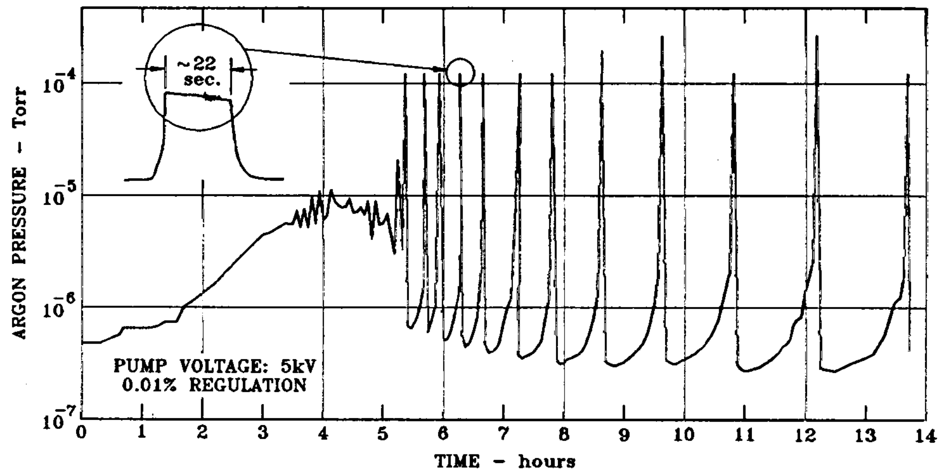
Diode sputter-ion pump





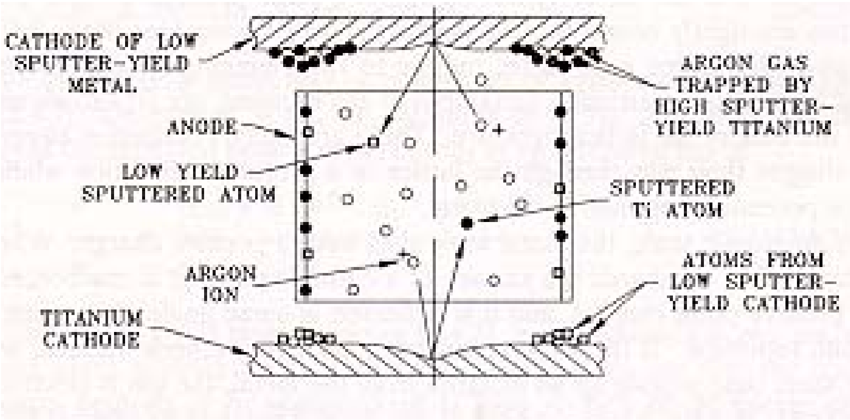
Argon Instability

- Diode ion pumps produce large periodic pressure fluctuations while pumping air or gas mixtures containing inert gases.
- These fluctuations are called "argon instability."
- Argon instability occurs both when pumping air at HV or UHV (1% argon by volume) and pure argon or other inert gases.
- Argon instability occurs when implanted or buried gases are released by sputtering.
- An "argon-stable" pump is one that can pump against a 100% argon leak without becoming unstable.



Differential Ion (Noble Diode) Pumps

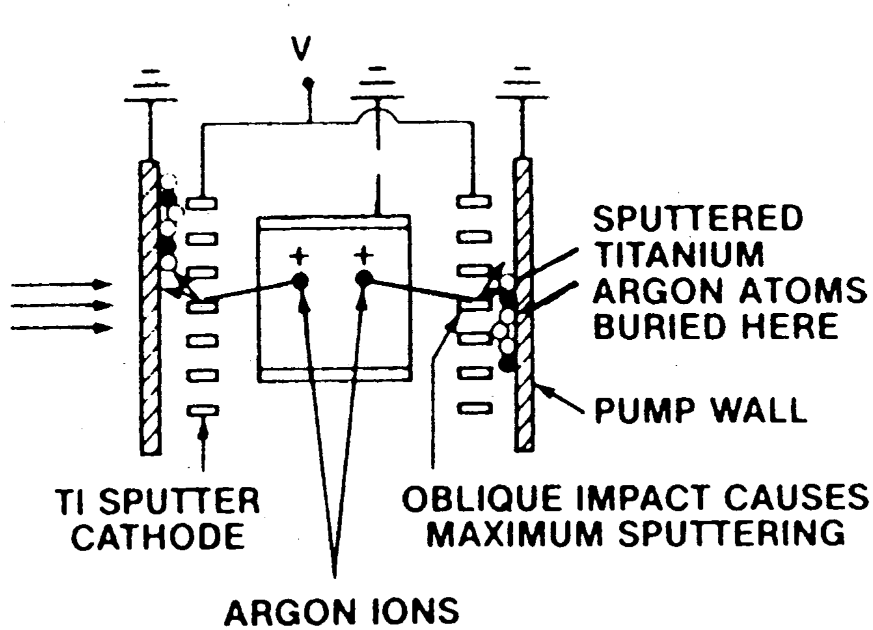
- The differential ion (D-I) pump design provides both air-stability and argon-stability, in a single pump.
- Most inert gases are pumped on the anode structure and at the peripheral areas of the cathode where the sputtering rate is so low that total reemission does not occur.
- These peripheral areas and the anode surfaces are readily reached by energetic reflected neutrals because the neutrals are not affected by the magnetic field.
- With a higher rate of energetic, reflected neutral formation, inert gas pumping speed is increased.
- To achieve high inert gas pumping speeds, differential pumping elements with one cathode chosen for good energetic neutral production (tantalum) and one chosen for its chemical reactivity (titanium) are used.

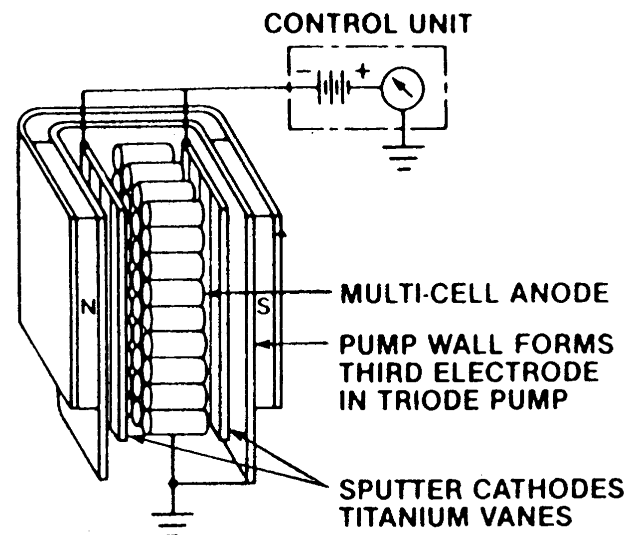


Pumping speeds of ion pumps for selected gases

Gas	Noble Diode	Diode
H_2	160%	220%
CO_2	100%	100%
N_2	85%	85%
O_2	70%	70%
H_2O	100%	100%
Ar	20%	5%
He	15%	2%
Light Hydrocarbons	90%	90%

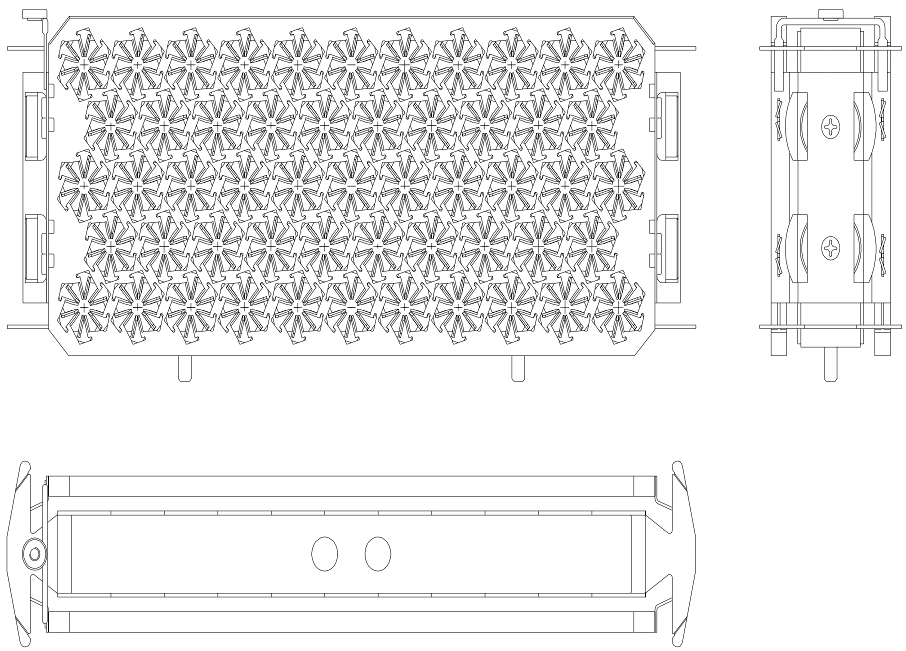
Triode ion pump



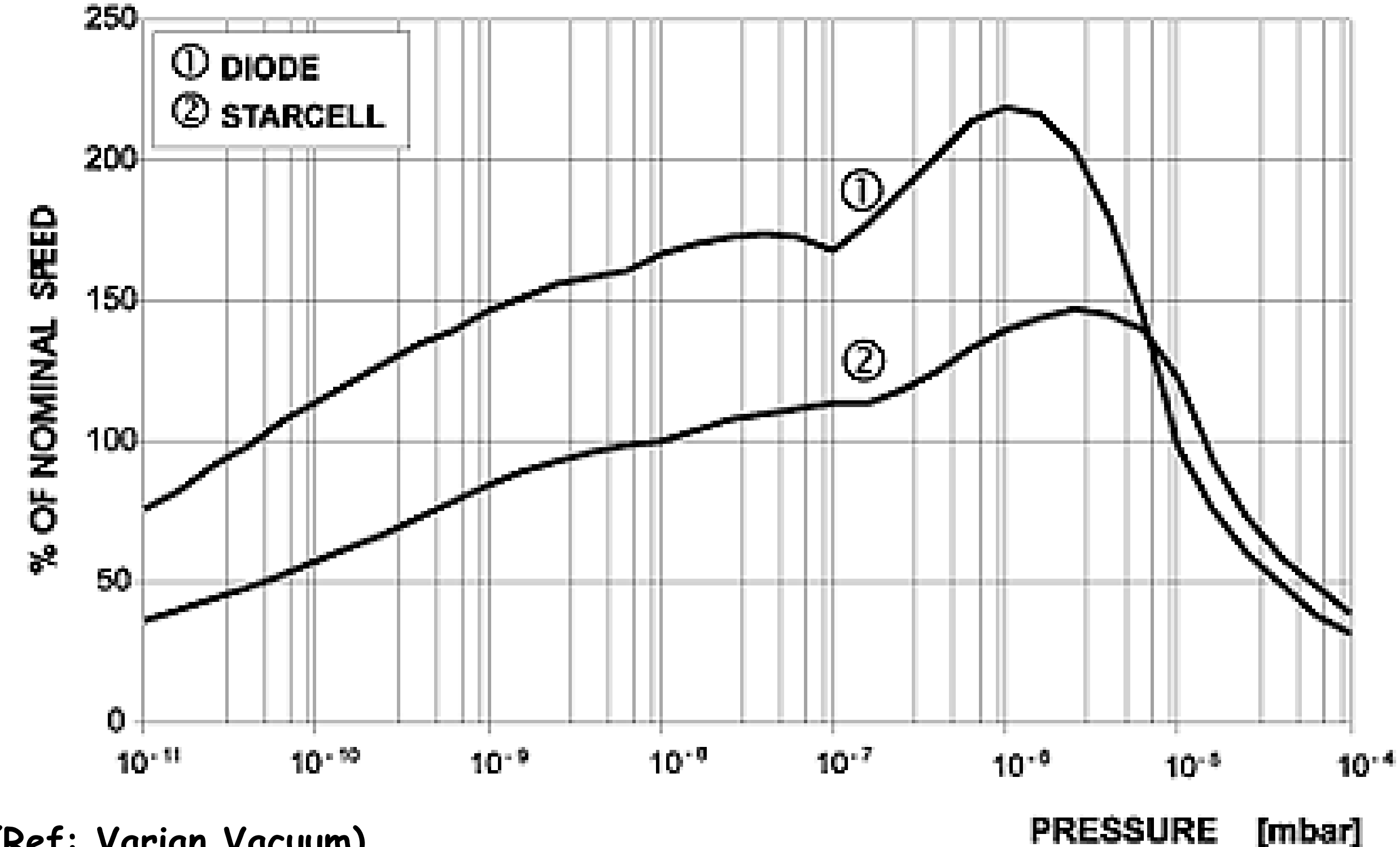


Starcell Electrodes

- Varian Starcell pump is a variation of the triode design.

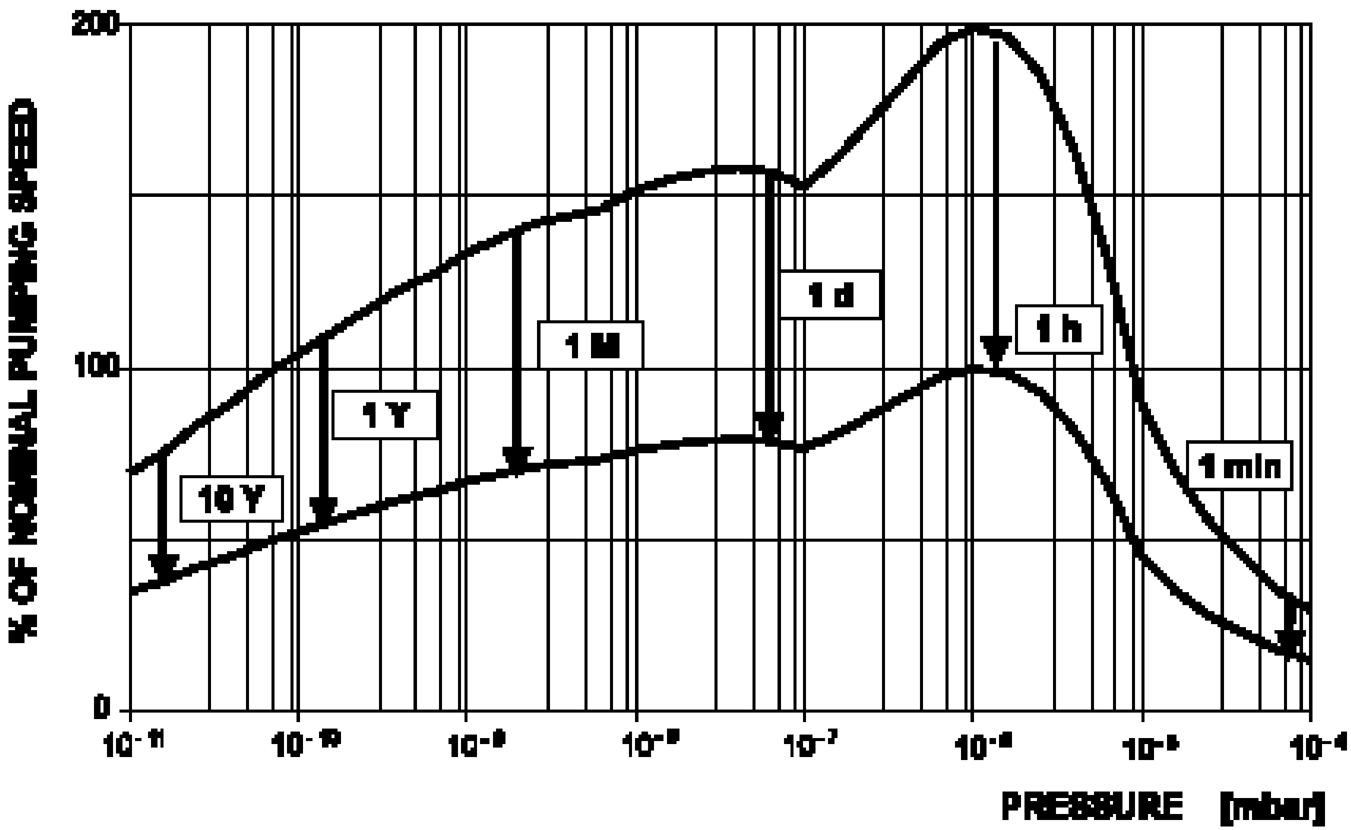


Speed curve for an ion pump



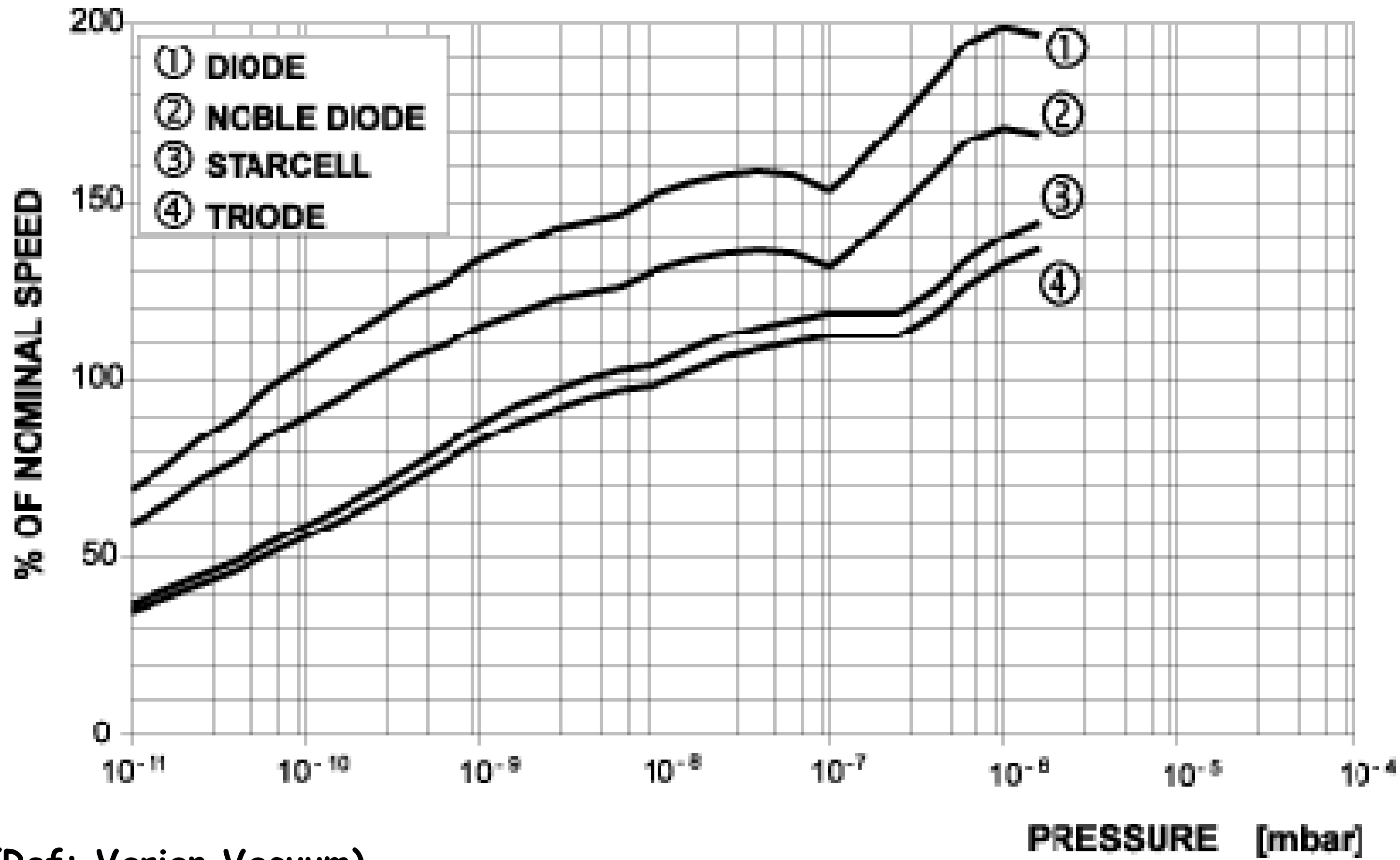
(Ref: Varian Vacuum)

Pump speed degrades with time



(Ref: Varian Vacuum)

Speed comparison of different styles of ion pumps



(Ref: Varian Vacuum)

Commercial sputter-ion pumps

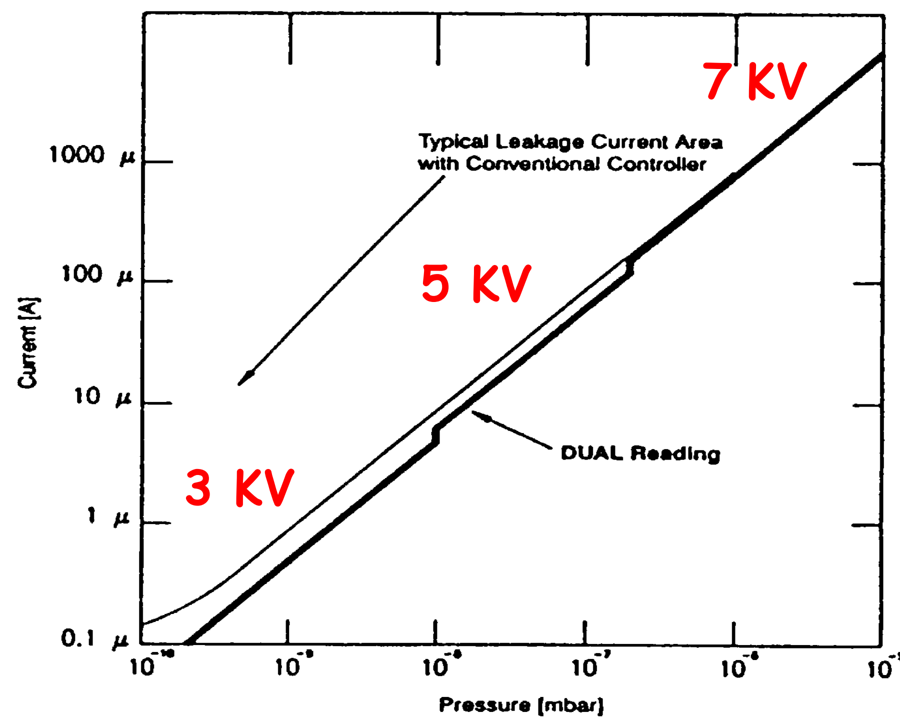
(Ref: Varian Vacuum)

Sputter-ion pump controller

(Ref: Varian Vacuum)

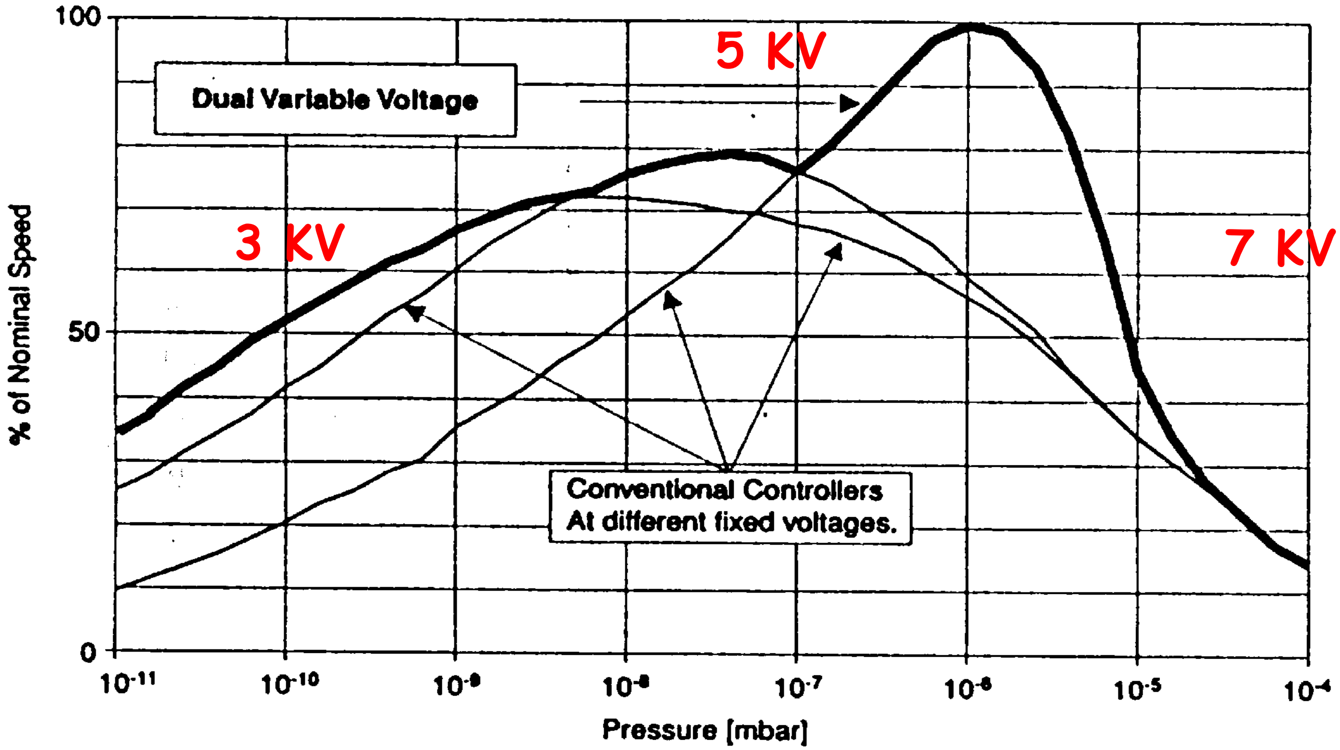
Sputter ion pump current may be used to measure pressure in the pump body

- Pressure is linearly proportional to current.
- At low pressures (<10^{-9} Torr), the leakage current effects the pressure reading.
- The displayed current is the total of the leakage in the power supply, cable connectors, feedthroughs, insulators, internal discharge, and working current.
- The new controllers with variable voltage capability improve this feature.



(Ref: Varian Vacuum)

“Variable Voltage Control” also improves pump performance

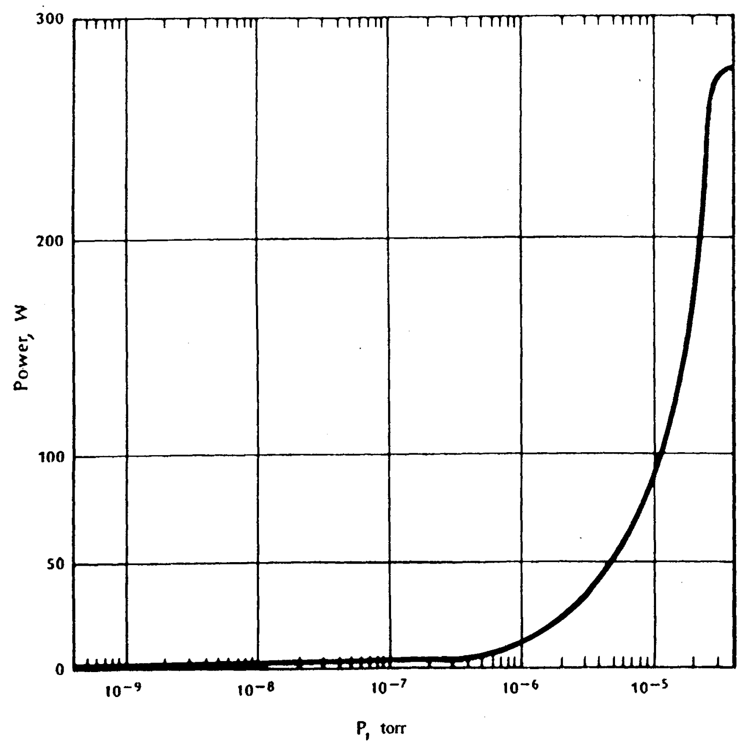


(Ref: Varian Vacuum)

Electrical characteristics of ion pumps

- It is important to match the power supply to the ion pump.
  - Too large a power supply can create overheating in the electrodes.
  - Too small a power supply will not be able to drive the pump at higher pressures.

- The power supply must provide voltage and current to the ion pump under a variety of conditions.



(Ref: Varian Vacuum)

Example – Ion Pumped Vacuum System SNS Linac

Current Design Features:

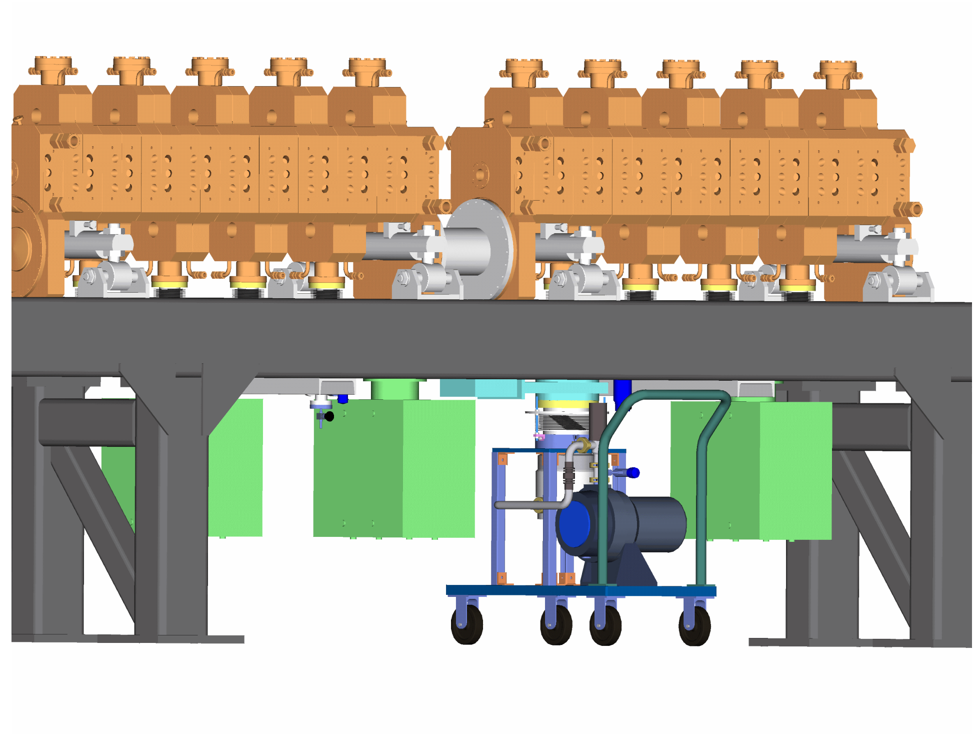
Accelerator Length

DTL: 36.5 m
CCL: 56.5 m

Design Vacuum Level: 10^{-7} Torr (with redundancy)

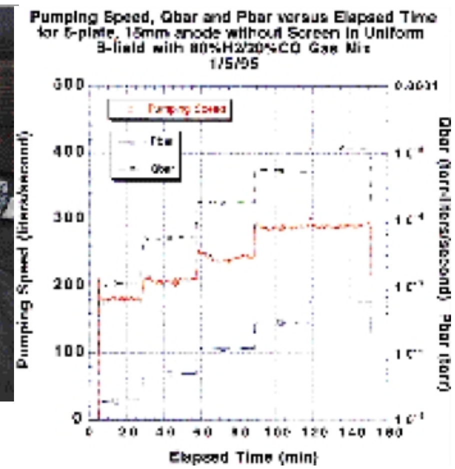
Total Ion Pump Speed: 20,000 L/s

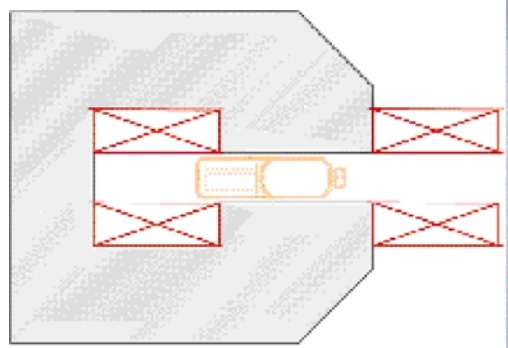
Number of Roughing/Turbo Carts: 15

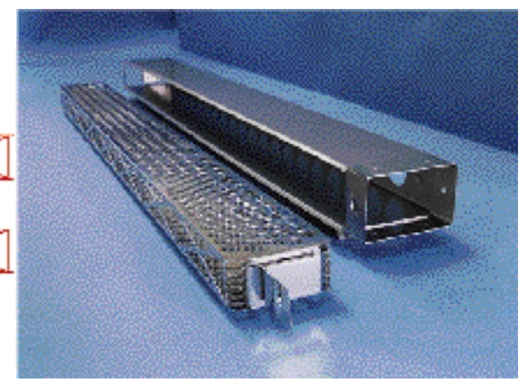


Distributed Ion Pumps (DIPs)

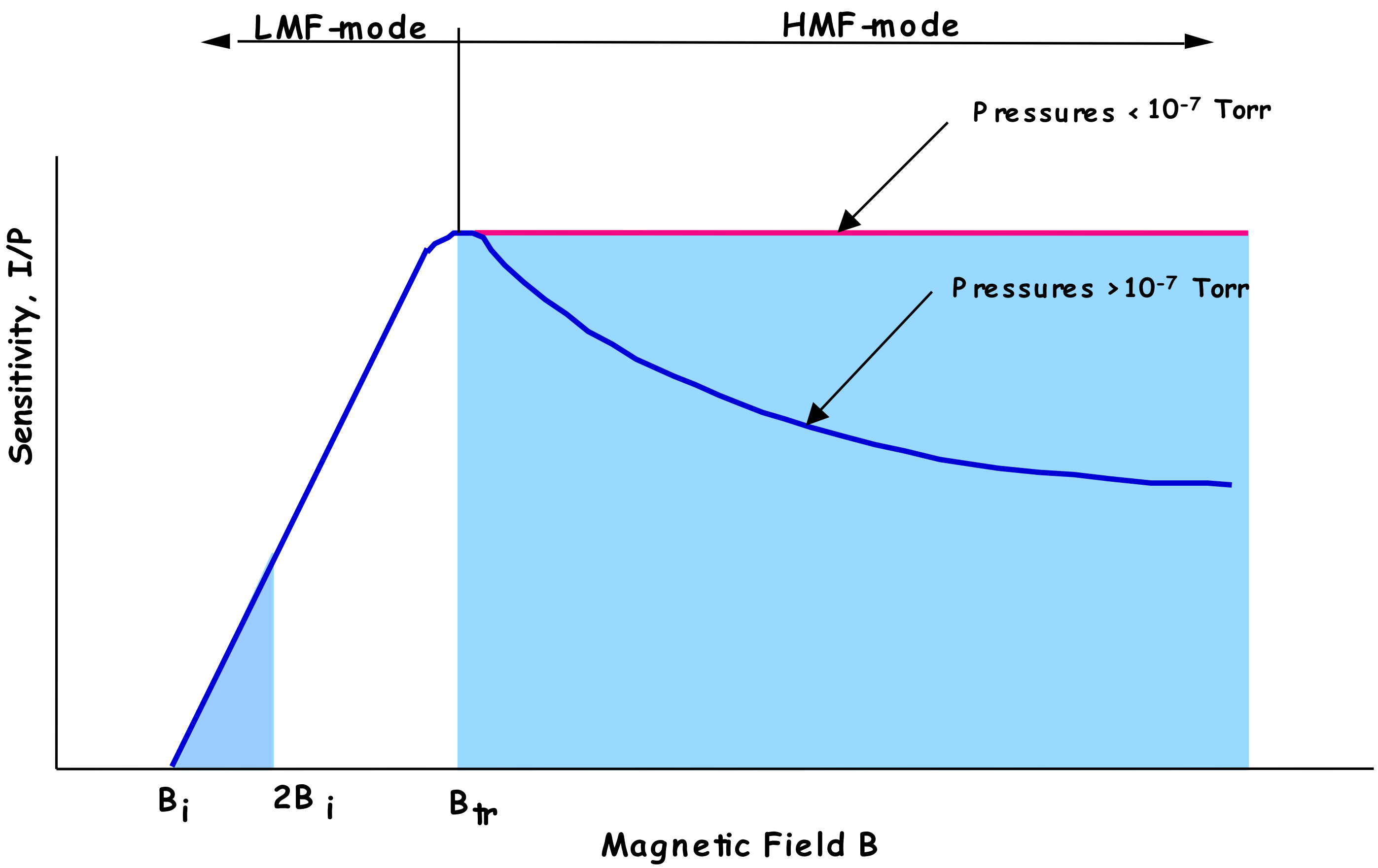
- Distributed ion pumps are often incorporated into storage rings.
- Distributed ion pumps utilize the stray magnetic field of the arc bend magnets.
- They provide effective distributed pumping close to synchrotron radiation gas desorption.







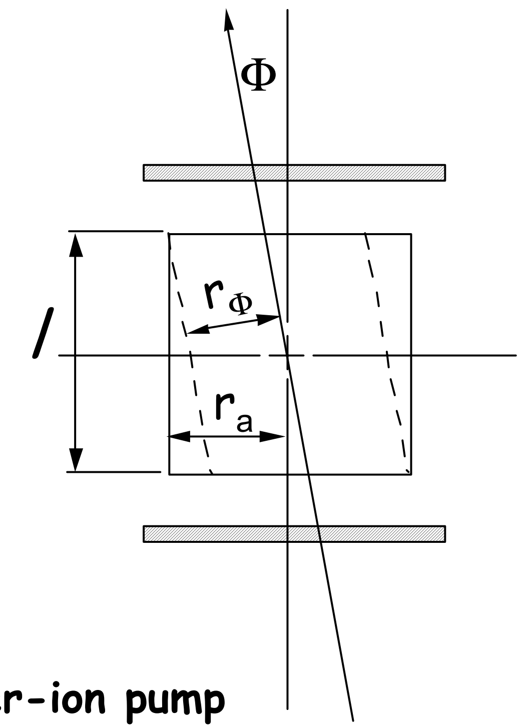
Pump Sensitivity (Discharge Intensity) vs. Magnetic Field



Formalism of Ion Pump Design

In cases where the magnetic field lines are misaligned with the cell axis, the electron cloud will be smaller than the anode radius.

$$r_\Phi = r_a \cos\Phi - 0.5\lambda \sin\Phi$$



Ref. "A new approach for computing diode sputter-ion pump Characteristics", Hartwig and Kouptsidis, JVST, Vol. 11, No. 6, 1974

Formalism of Ion Pump Design (continued)

Magnetic Field at the Ignition Point

$$B_i = \frac{300}{r_a}$$

where a = gap (cm)
r_a = cell radius (cm)
l_a = anode length (cm)
P = pressure (Torr)
U_a = anode voltage (V)
B = magnetic field (Gauss)

Magnetic Field at the Transition to HMF-mode

$$B_{tr} = \frac{7.63\sqrt{U_a}}{r_a P^{0.05}}$$

Effective Cell Length

$$l_{eff} = l_a + 0.5\alpha$$

Formalism of Ion Pump Design (continued)

Unsaturated Nitrogen Pumping Speed of one cell

$LMF - \text{mode},\ B_i \le B \le 2B_i$

$$S_1 = 6.27 \times 10^{-5}\left(1 - \frac{1.5 \times 10^6 P}{1 + 4 \times 10^6 P}\right) P^{0.2} l_{eff} r_a^2 B_i (B - B_i)$$

$LMF - \text{mode},\ 2B_i \le B \le B_{tr}$

$$S_1 = 1.56 \times 10^{-5}\left(1 - \frac{1.5 \times 10^6 P}{1 + 4 \times 10^6 P}\right) P^{0.2} l_{eff} r_a^2 B^2$$

$HMF - \text{mode},\ B \ge B_{tr}$

$$S_1 = 9.1 \times 10^{-4}\left(1 - \frac{1.5 \times 10^6 P}{1 + 4 \times 10^6 P}\right) P^{0.1} l_{eff} U_a \left(1 - 1.5 \times 10^4 \frac{\sqrt{(B - B_{tr})}\, r_a P}{U_a}\right)$$

Saturated Nitrogen Pumping Speed (after Q = 2 x 10^{-6}S Torr-liters/sec)

multiply above equations by $\left(0.75 - \frac{2 \times 10^{-10}}{P}\right)$ valid for $P > 3 \times 10^{-10}$ Torr

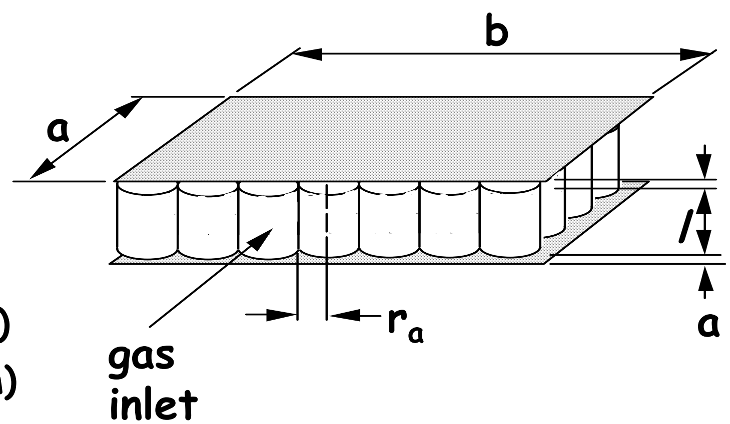
$S_{sat} = 0$ valid for $P < 3 \times 10^{-10}$ Torr

Formalism of Ion Pump Design (continued)

Nitrogen Pumping Speed for n cells

$$S_n = nS_1$$

Effective Nitrogen Pumping Speed due to conductances of the gaps between the anode and the two cathodes.



$$S_{eff} = S_n\left(\frac{\tanh D}{D}\right) \quad \textit{where} \quad D = \frac{ka}{7.85\alpha}\sqrt{\frac{S_n}{ab}}$$

a = depth of pump unit (cm)

b = length of pump unit (cm)

α = gap (cm)

k = factor = 1 if pump is open on one side

= 0.5 if pump is open on two sides

Formalism of Ion Pump Design (continued)

Effective Nitrogen Pumping Speed for N units at the flange

$$\frac{1}{S_p} = \frac{1}{NS_{eff}} + \frac{1}{C}$$

where S_p = effective nitrogen pumping speed (liters/sec)

N = number of pumping units

C = conductance of the pump chamber (liters/sec)